focus: AUV LAB

MIT SEA GRANT

OUR STORY

Testing Odyssey IV

SEA SQUIRT: *first AUV Lab vehicle*

1989

PROGRAM MISSION

Founded in 1966 by Congress, the National Sea Grant College Program is a network of 30 programs working to promote the conservation and sustainable development of our marine resources through research, education, and outreach. Sea Grant is funded by the U.S. Department of Commerce's National Oceanographic and Atmospheric Administration (NOAA).

The Massachusetts Institute of Technology was designated as a Sea Grant College in 1970—the first private institution of higher learning to be appointed as such. During the past several decades, MIT Sea Grant has led the way in developing technologies to advance ocean science and the wise use of marine resources. In pursuit of this goal, the program promotes research in areas essential to the continuing evolution of scientific and technological advances, providing ever-increasing accuracy and range in exploration, data gathering, analysis, and the improved understanding of ocean and marine processes.

ODYSSEY *launched*

1992

ODYSSEY *goes to Antarctica*

1993

My days in the AUV Lab were some of the most exciting of my life.
We participated in the birth of a new technology, and a new industry.

JAMES BELLINGHAM, CHIEF TECHNOLOGIST, MONTEREY BAY AQUARIUM RESEARCH INSTITUTE

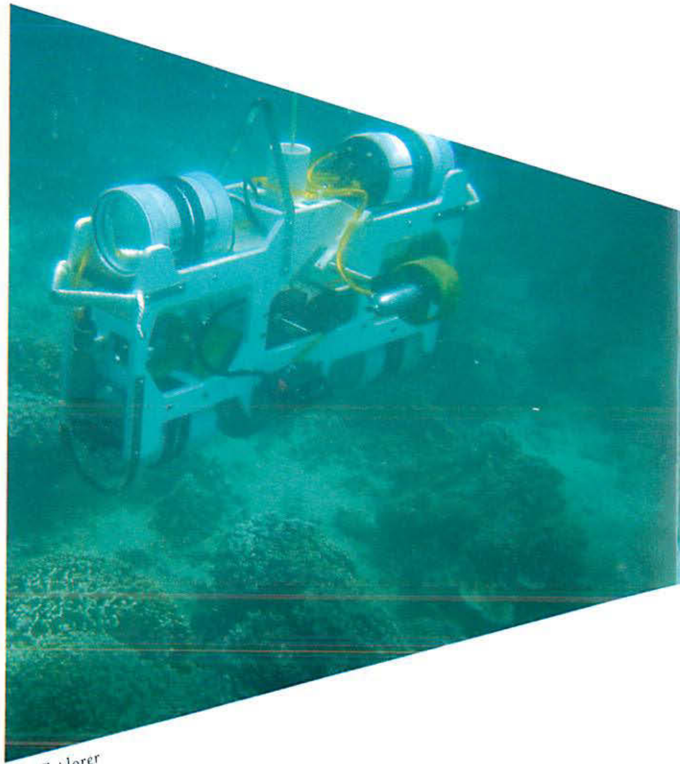
AUV LAB HISTORY

MIT Sea Grant's Autonomous Underwater Vehicles (AUV) Laboratory got its start in 1989 with a challenge: to build an AUV for less than $100k that could dive to 6,000 meters and be lifted by two people—of average academic build. That challenge, from MIT Sea Grant director Chrys Chryssostomidis, led to a revolution in the design and operation of AUVs–small, inexpensive, artificially intelligent, robotic submarines for undersea exploration.

AUVs and other robots offer opportunities for exploration and discovery previously impossible in deep and often treacherous oceans. Our AUVs go where humans can't venture and where remotely operated vehicles (ROVs) may only voyage with great expense.

Since the Lab's inception, our AUVs have traveled the globe, conducting missions under the Arctic Sea, in the Antarctic, on the Juan de Fuca Ridge, off the coast of Australia, in the Haro Straits, the Labrador Sea, and the Aegean, as well as closer to home, in the Charles River and Cape Cod Bay. The ease with which our AUVs can be adapted for different pursuits means that they've been employed in under-ice mapping, investigating tidal mixing, studying biological communities, tracking invasive species, and aiding marine archeologists in their searches.

By the mid-nineties, our AUVs had become so popular with the scientific and defense communities that the demand for vehicles exceeded our production capacity. As a result, in 1997 the Lab transferred



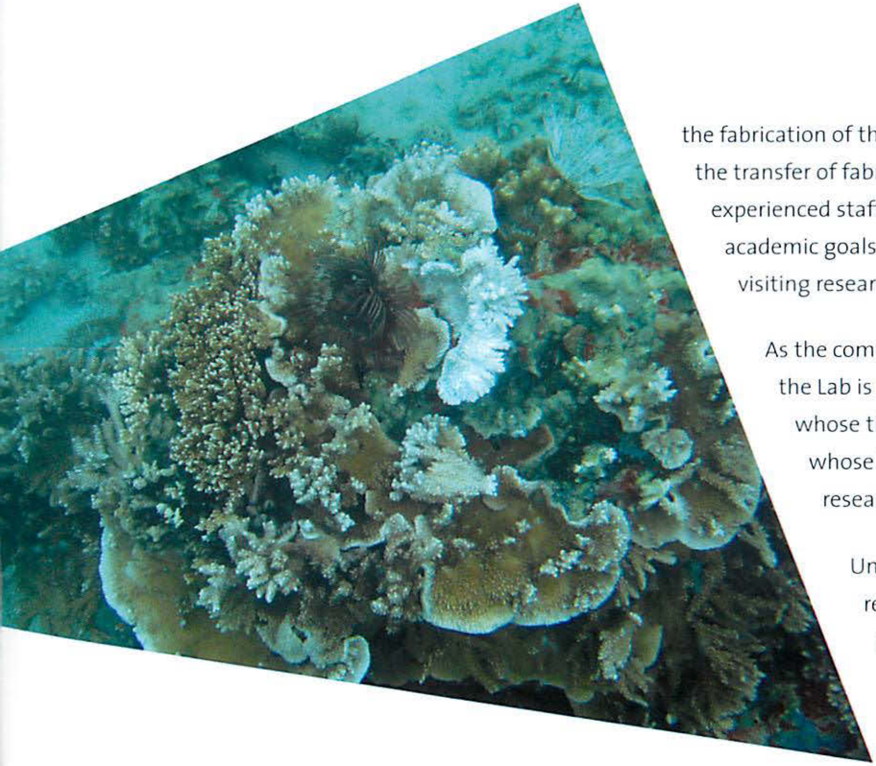
Reef Explorer

ODYSSEY II *studies sea-ice mechanics in Arctic*

1994

ODYSSEY II *deployments to deep water: Juan de Fuca Ridge and Bermuda* · *4 new* ODYSSEY IIbs *built and loaned to collaborators (Navy, WHOI, industry)*

1995



the fabrication of the *Odyssey* class of AUVs to a new commercial spin-off, Bluefin Robotics. Along with the transfer of fabrication, this commercial spin-off meant that we also said goodbye to our most experienced staff. However, this was a natural evolution and ensured that the Lab would maintain its academic goals and continue to provide an environment in which students, budding engineers and visiting researchers could push the envelope in developing new technologies.

As the comments from students, staff, and former staff illustrate in these pages, the value of the Lab is measured not just in the technology we produce, but in the engineers and scientists whose time here prepares them for varied careers in marine engineering. Those individuals, whose labors have brought these new technologies to light, are as much the fruits of our research as our signature little yellow submarines.

Under our current 10-year strategic plan, we have been successfully rebuilding and refocusing the AUV Lab. Our projects are consistently of a highly collaborative nature, as we work with academia, industry, and government, both nationally and internationally. We also maintain close ties with Bluefin, which was acquired by Battelle in 2005 and currently employs more than 60 people at its headquarters in Cambridge and operations facilities in Quincy, Mass.

ODYSSEY IIb *studies frontal mixing in Haro Strait, off Vancouver Island*

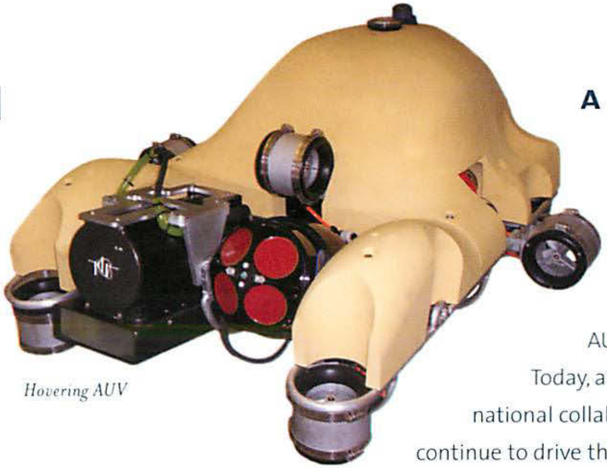
1996

Search for giant squid off coast of New Zealand · Commercial spin-off: Bluefin Robotics is incorporated

1997

We're here for the summer to add a water sampler to the Sea Perch. Since the Sea Perch is so small, it was hard to create the water sampler. There was a lot of error in the trial and error. And then on Wednesday we tested it out in Gloucester and it worked. We were shocked!

HOMA DUCASSE, SENIOR AT EVERETT HIGH SCHOOL, AND AARON KING, SENIOR AT CAMBRIDGE RINDGE AND LATIN HIGH SCHOOL



Hovering AUV

AUV STRATEGIC PLAN SUMMARY

Our plan includes developing the next generations of AUVs, building a strong field team to conduct critical ocean experiments, and designing and implementing near-real-time, multi-user underwater communications systems. These efforts involve large-scale collaborations to address critical scientific problems.

AUVs have played a significant role in MIT Sea Grant's research objectives for roughly a dozen years. Today, an increased focus on oceanographic data needs, advances in enabling technologies, regional and national collaborations for more synoptic research programs, and the challenges of remote, extended missions continue to drive the development of the AUV as an essential ocean research tool.

Labrador Sea mission to study bottom water formation · Generic Oceanographic Array Technology Sonar (GOATS) expedition to Elba, Italy — *Bluefin Robotics facility opens*

1998 — 1999

DEVELOPMENT

Student building a Sea Perch

Since its inception, the Lab has attracted undergraduate and graduate students keen to address the engineering challenges of ever-evolving AUVs. This tradition continues, as does our collaboration with visiting students and researchers.

We are also committed to nurturing the engineers and scientists of tomorrow by focusing on K-12 education. Through our Sea Perch program, we teach teachers how to build remotely operated vehicles (ROVs). Students then get hands-on experience in building ROVs for their own underwater experiments. We have partnered with numerous other Sea Grant programs in this project and have also collaborated with Boston's Museum of Science, The New England Aquarium, engineering societies, the Sea Grant Educators' Network, and the Link Foundation. Our ultimate goal is to develop a national model for a self-sustaining K-12 Sea Perch program.

They all plan on going into engineering.

MARTY ROTHWELL, A TEACHER AT CHANTILLY ACADEMY HIGH SCHOOL, FAIRFAX, VIRGINIA, TALKING ABOUT HIS STUDENTS WHO BUILT A SEA PERCH.

1995-2000: *Development and demonstration of Autonomous Ocean Sampling Network (AOSN)* · ODYSSEY IId *participates in marine archaeology missions off coasts of Greece and Italy*

2000 — 2001

I've spent years of my life building these vehicles and then sending them off on their own into deep water. It's a dangerous and unpredictable environment, always surprising. We keep pushing our AUVs to their limits, and sometimes things go wrong. After losing contact with our Odyssey II *one difficult*

day on Lake Michigan, I thought it was lost forever; hours later, a call came in over the ship's radio: "Did anyone lose a yellow dolphin?" It's getting past the problems, to those few days when everything finally runs smoothly, that keeps me excited about my work. JIM MORASH, AUV LAB RESEARCH ENGINEER

ASPIRATIONS

AUVS TODAY

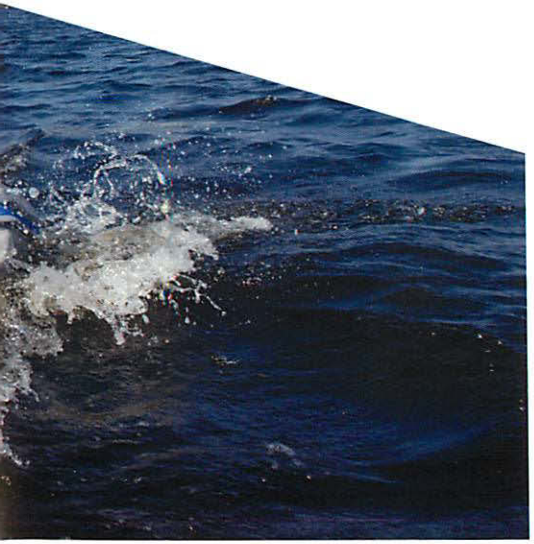
Our newest generation of AUVs is the *Odyssey IV* class vehicle, a hovering craft (HAUV) that can maintain its position even in strong waves and currents. This is a critical modification of our previous AUVs, whose torpedo shape was designed for optimal cruising. Our new vehicles can be built in a range of sizes. One prototype, funded by the Office of Naval Research (ONR), is a suitcase-sized HAUV built for homeland security applications. We developed another prototype, CETUS™, after Lockheed Martin Corp. requested a vehicle that could search for objects in the ocean.

The *Odyssey IV* class AUV responds to the growing need for more capable, more maneuverable, more accessible AUVs and reflects the Lab's years of field experience. The smooth, faired shape is derived from the streamlined body of the successful *Odyssey II* class AUV, allowing energy-efficient high-speed transits and quick missions to great depths. The vehicle's size and weight make it deployable from small, less expensive boats, while still leaving room for a substantial science payload.

With a depth range of 6,000 meters, this AUV can cover 97% of the oceans' expanse. It is passively stable at high speed and capable of precise hovering. Planned payloads include a high-resolution stereographic digital camera, a multibeam sonar, sample return devices, a mass spectrometer, and a manipulator.

I started with the AUV Lab as a UROP student in my sophomore year and continued throughout my undergraduate time and in my Masters, when I designed and built a small-scale spar buoy to be used as an offshore platform for wireless, Ethernet communications hardware. The AUV Lab did an excellent job of fostering in me an enthusiasm for and understanding of marine robotics and naval architecture.

MEGHAN OVERSTAKE, NAVAL ARCHITECT AND RESEARCH ENGINEER, EXXONMOBIL UPSTREAM RESEARCH CO.



Katrina on the Charles River

In addition to AUVs, we design other marine robots as well, such as surface craft. After the devastating U.S. hurricane of 2005, the Lab developed a diesel-powered surface vessel as a disaster response platform. Funded by ONR, this 10-foot vessel is known as *Katrina*. It uses GPS and radar to navigate, can withstand strong wave forces and operate for up to 48 hours while conducting *in situ* analysis in the wake of hurricanes and other disasters. Its computer- controlled winch can lower water quality probes equipped with sensors up to 100 feet and collect a "vertical profile" of temperature, salinity, pH, and other measurements.

We have also developed a hybrid AUV/ROV. Known as the *Reef Explorer*, this vehicle was conceived to conduct missions in shallow water and is being used to explore coral reefs in a NOAA-funded project in Hawaii. Equipped with a color camera and a wireless radio link to shore (via a short vertical tether and antenna float) the *Reef Explorer* also provides live video from up to 90 feet underwater and is limited only by the vertical cable length in this capacity. As part of our K-12 education activities, we are streaming data back to classrooms, allowing students to explore the reef virtually and send simple commands to the AUV.

The Lab is a great training ground for my students. It gives them an opportunity to work on everything from theory to implementation and experimentation, all under one roof. We have a kitchen too, so they can learn to cook while waiting for their computers to produce results.

MILICA STOJANOVIC, MIT SEA GRANT PRINCIPAL RESEARCH SCIENTIST

AUVS TOMORROW

Freeing underwater vehicles from tethers was a breakthrough revolution. The next revolution in underwater technology will come as we develop the technology for AUVs to work at vast distances from shore for long periods, communicating with each other, conducting complex sensing and chemical analysis, and performing types of manipulation currently not possible. These are challenges we are addressing in our research now.

As AUVs take on tasks previously conducted by humans, they must also, like people, be able to work in teams and communicate with each other. While underwater acoustic communication is possible now with AUVs, it remains inefficient. To improve this capability, we are developing a simulation and rapid prototyping environment called the reconfigurable modem (rModem). Environmental monitoring, fisheries research, and the offshore oil industry will all benefit from these improvements.

In helping to meet U.S. energy needs, AUVs can also be expected to be called into service in ultra-deep waters. Given the prohibitive costs of building and maintaining platforms in such deep waters, the supporting infrastructure for wells will move shoreward. Meanwhile, maintaining and repairing the wells will require a safe, cost-effective, and environmentally sensitive technology. AUVs are the

Forum focuses on AUVs in deep-water oil and gas industries
2006

Searching for Minoan shipwrecks off the coast of Greece

logical choice for operating on the ocean floor, in remote locations, and at depths greater than 4,500 feet. The HAUV that we have developed sets the stage for a future scenario in which networks of vehicles could travel long distances and remain deployed for many months while servicing deep-water wells.

To conduct this routine maintenance, repair, and monitoring for the oil and gas industries, AUVs will require improved undersea robotic manipulation. Our initial research efforts in this area will most likely rely on conventional technology. However, we will also continue to experiment with biomimetics—taking inspiration from biological systems to design new engineering systems. This work will draw on our research with flapping foils, including the *Roboturtle*, a turtle-inspired vehicle known for its flexibility and robust maneuverability. Improved manipulation will also be essential for improved docking, which will allow vehicles to download data and recharge—key for long-term deployments of vehicles. Our research addressing ultra deepwater challenges has recently received funding from Chevron.

For improved AUV navigation and control, we will also be developing inexpensive, very low-power sensors, capable of passively detecting and identifying objects and flow patterns. This research, which also draws on biomimetics, will produce pressure sensors that emulate the capabilities of the lateral line in fish and will be of particular use with multiple vehicles in shallow water and/or cluttered environments. Such sensors will allow AUVs to vastly improve their capacity for ocean observation, environmental monitoring, and fisheries observation.

REEF EXPLORER *conducts mission in Hawaii*

2007 2008

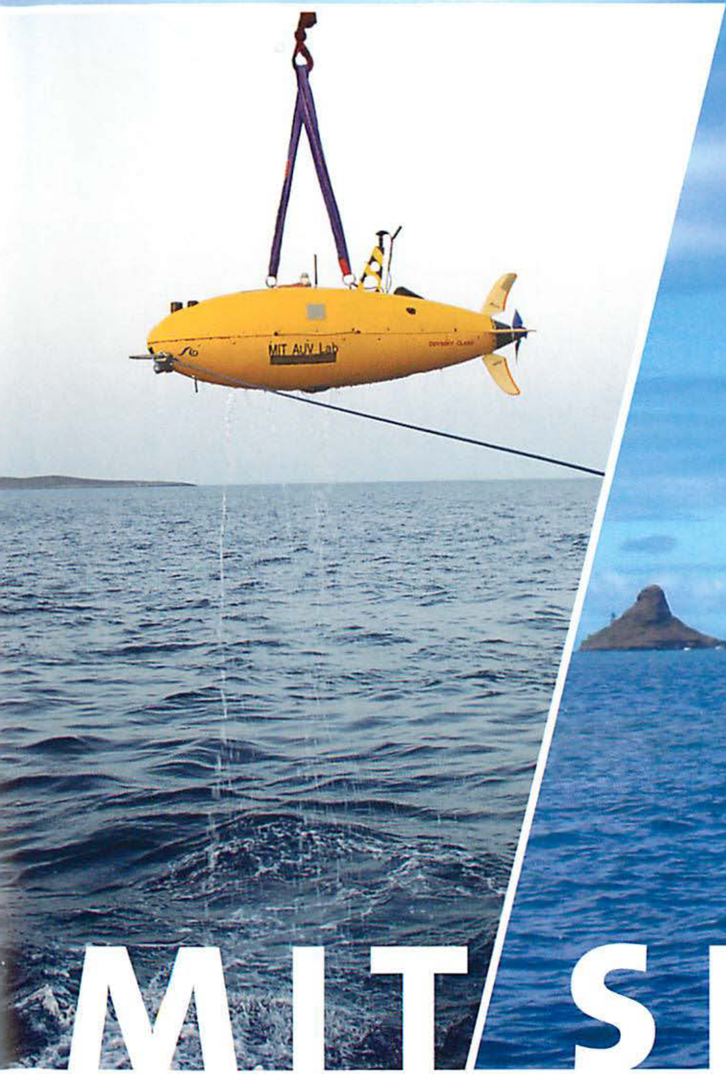
Working with the AUV Lab has been a great opportunity to get out in the field and really use what I had learned for a very exciting project. Where else can you spend a month on a ship in Greece, playing with robots and looking for ancient shipwrecks?

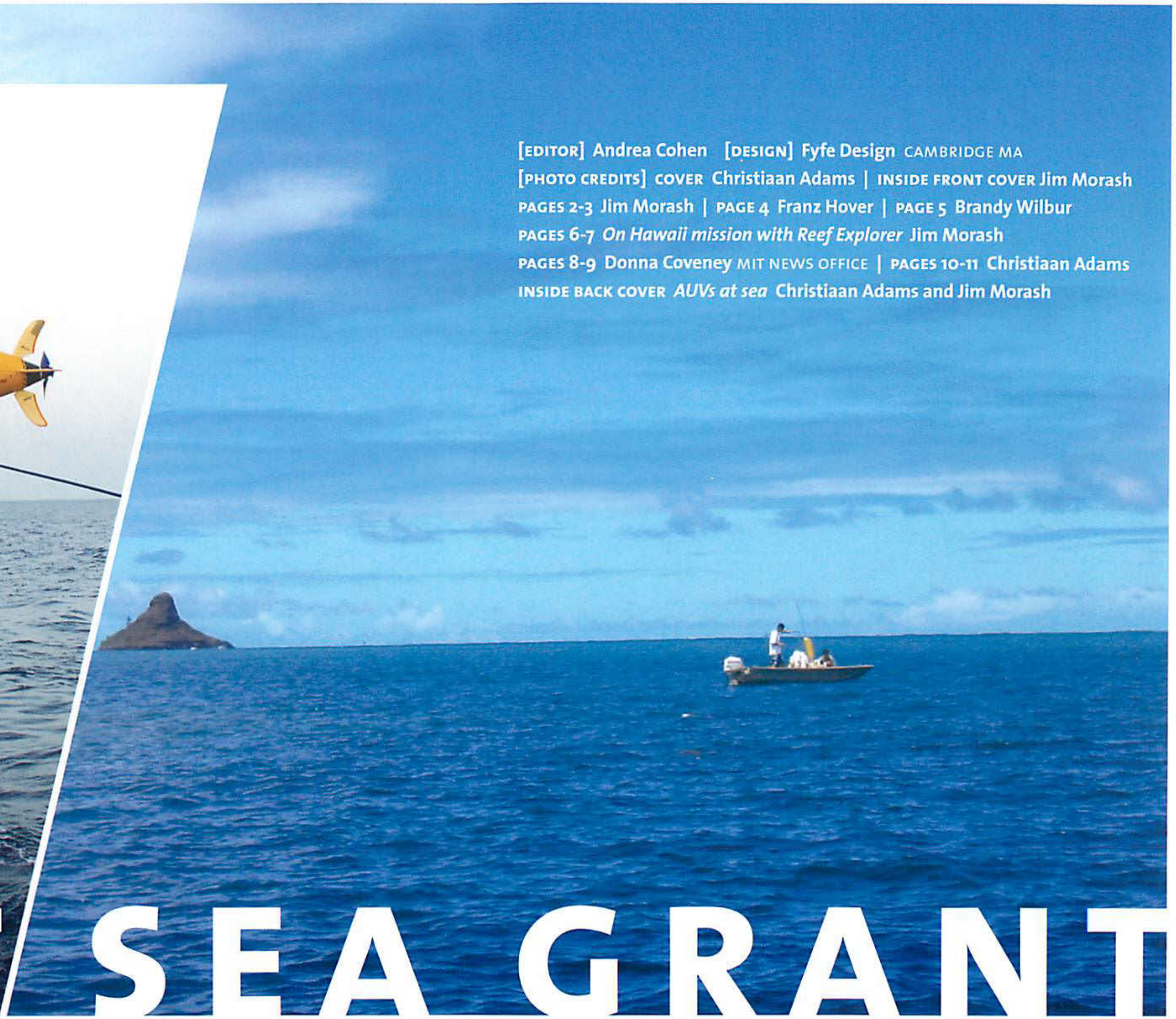
CHRISTIAAN ADAMS, GOOGLE EARTH OUTREACH TEAM MEMBER

Thus far, our collaborations have produced chemical sensors to be deployed on board our AUVs. Our vehicle *Kemonaut* was designed to autonomously measure key parameters of fresh or marine waters *in situ* and to transmit such data to shore in real time. This enables both real-time mapping of water chemistry in three dimensions as well as adaptive sampling strategies in response to observations. The NEREUS mass spectrometer we developed will allow us to measure concentrations of methane, oxygen, and carbon dioxide, as well as argon and various volatile solvents such as benzene. With future improvements, we will also be able to target metabolic gases such as hydrogen and nitrous oxide. Our goal is to make the vehicle capable of adaptive sampling, which would allow it to detect and follow a high concentration of some chemical of interest. This would be of great value in responding to oil spills or other emergencies.

With long-term AUV deployments, we will also need vehicles that can not only sense chemicals, but also conduct sophisticated analysis and send that data back to researchers. We are at the beginning stages of exploring how such an underwater "chemical factory" might operate.

Simply put, teaching new subs new tricks means creating new technologies. So that's what we're doing. Check us out online at http://auvlab.mit.edu. Or come visit and see what's keeping our engineers up late these days.





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INSIDE BACK COVER *AUVs at sea* Christiaan Adams and Jim Morash

MIT SEA GRANT

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Sea Grant

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